^ MATH MEETS BIO IN UNCG COLLABORATION Rueppell, Rychtář, Shivaji, Pauli, Kalcounis-Rueppell, and Rowell (left to right).

MATHEMATICIANS WALK ON THE WILD SIDE IN GROWING UNCG FOCUS

What do California field mice, delphacid planthoppers, and honeybee queens have in common? UNCG mathematicians.

At UNCG, an emerging cluster of mathematicians and their students are collaborating with biologists here and at other universities. The field is called math biology or biomathematics.

They are working together to analyze massive stores of scientific data, model how animals behave, and better understand how life functions at every level — from the interior of a cell to the borders between ecosystems.

"Math biology is a very hot applied field," says Ratnasingham Shivaji, H. Barton Excellence Professor and head of the Department of Mathematics and Statistics. "It's different from previous, traditional applications of differential equations in physics and engineering. Ideas and techniques from many diverse branches of mathematics are needed to answer questions arising in biology. It's an exciting challenge."

Over the last 20 or 30 years, technological advances have opened up new opportunities for mathematicians to collaborate with biologists, physicians, and others in the life sciences. Biological systems — whether it's how the microscopic parts of a cell interact with each other or how animals behave — are extraordinarily complex. But with advances in computing power, it's become possible for researchers to formulate those systems mathematically and actually solve those complex problems.

What would have been impossible to solve on a chalkboard a few decades ago can now, often, be run on a computer. The results allow mathematics to describe and predict many biological phenomena and also provide biologists with new tools and insights to approach their work.

MOUSETRACKER PROGRAM SNARES STUDENTS

Some of the earliest formal math biology work at UNCG began with a 2006 National Science Foundation grant to fund the Interdisciplinary Training for Undergraduates in Biology and Mathematical Sciences (UBM) program. That grant helped put together biology professor Matina Kalcounis-Rueppell and mathematics professor Sebastian Pauli. Kalcounis-Rueppell studies the behavior of nocturnal animals; Pauli is focused on number theory.

Kalcounis-Rueppell showed Pauli thermal video images she had of California field mice, which are active at night. She also had audio recordings. She wanted to better understand the mice's behavior and how the sounds they make — mostly above the range of human hearing — might be related to that behavior.

But sitting through thousands of hours of video, cataloging mice movements, and trying to tie movements to the sounds they make was a gargantuan task. And once that was complete, it would still be a challenge to extract useful data from the results.

"We needed a way to automate and quantify both spatial and temporal aspects of the behaviors that were in the video," Kalcounis-Rueppell says.

Enter Pauli. "I said, 'I know we can automate that.' The computer can watch them and process the data in different ways."

Pauli's students wrote software that could identify mouse images on the video, distinguishing them from other objects, and then track their movements over time. Computer science professor Shan Suthaharan was also involved.

The software must distinguish mice from other moving objects in the frame and also do things like keep track of a specific mouse if it disappears behind a tree for a few moments. When it re-emerges, it should be tracked as the same mouse, not a new animal.

The software allows Kalcounis-Rueppell to answer questions such as "do the vocalizations of the mice change when they're near their nest?"

"We are interested in understanding the behavioral context of when mice make ultrasonic sounds," she says. "Are the sounds being made when the mice are close to the pups in their nest? If they are, then those ultrasounds may be useful for parental care."

As Kalcounis-Rueppell's research questions evolve, Pauli helps undergraduate students write new computer code to perform the analyses that she needs. He helps them think about how to frame their approach both from a software standpoint and, importantly, from a mathematical standpoint.

"It really gives them an opportunity to apply things they have done," Pauli says. "They actually produce something real, not just an assignment, but something that means something."

GROWING INTO A NEW FIELD

For math faculty members, opportunities for interdisciplinary collaboration in math biology have bloomed in the last few years.

Dr. Jan Rychtář came to UNCG in 2004 expecting to focus on functional analysis but within a few years found himself pulled toward problems in biology. "There is something at UNCG that allowed the switch and made the switch possible," he says. He cites opportunities to collaborate with colleagues in the life sciences, as well as research funding that encourages interdisciplinary work. "The collegiality between professors is really good here."

At least eight faculty in the Department of Mathematics and Statistics are currently working on math biology projects.

The newest of that group is Jonathan Rowell, an assistant professor who came to UNCG in 2012 to focus on math biology. He has an extensive background in the field. He earned his PhD in applied mathematics at Cornell University and picked up a minor in ecology along the way. He then did a yearlong postdoc at the University of Tennessee's Department of Ecology and Evolutionary Biology and spent three years in the biology department at UNC-Chapel Hill before coming to Greensboro.

For Rowell, it's not about math for math's sake. "It becomes really important as someone who is a biomathematician to figure out, 'What is the implication? What does that mean biologically?'"

Currently, he's focusing on how individual animal movements affect animal populations as a whole. "There's a lot of promise here," he says of the math biology focus at UNCG.

HOW MANY MATES FOR THE QUEEN?

That promise of math biology not only means opportunities for faculty, but also for students, including undergraduates.

Recently, five undergraduate students, working under the supervision of Rychtář and biology professor Olav Rueppell, tackled honeybee queen mating behaviors.

After learning some basic honeybee biology, the students — a biology major, a physics major, a computer science major, and two math majors — built a mathematical model of how genetic diversity in a honeybee colony changes depending on how many times the queen mates.

Mating, in evolutionary terms, is expensive, Rueppell explains; there are costs and benefits. And with scientists and others worried about declining bee populations, new insights on honeybee mating could have important practical implications.

"That was a very productive project," he adds, "with implications for general mating behavior in insects."

The end of summer 2015 marked the close of UNCG's second NSF-funded Math-Bio Research Experience for Undergraduates. The program, which has hosted approximately

20 undergraduates thus far, lets students stretch beyond their disciplines, conduct laborious research, and deliver presentations on their findings.

However, the undergrad research collaboration is actually in its ninth year when you factor in the seven-year UBM program that preceded it. That program took in eight UNCG undergraduates every year, partnering math and biology students in interdisciplinary research teams. UBM resulted in 25 awards, 41 papers, 57 international presentations, 50 national and state level presentations, and over 150 presentations at the regional level.

Over nine years, these students have applied math to study different aspects of insect behavior, examined the evolution of cooperation in social organisms, developed a new way to analyze and understand gene sequences — and more.

UNDERGRADUATE OPPORTUNITIES **Rowell, Rueppell, and Rhyctář head up the NSF-funded Math-Bio Research Experience for Undergraduates. UNCG undergraduate math-bio collaborations are now in their ninth year.**

Rychtář says the work on genetic sequences, in particular, has huge potential across a range of fields to improve how scientists analyze how genetic sequences are expressed in living organisms.

As Rychtář and his students develop mathematical models for biological systems or behaviors, biologists like Rueppell conduct experiments and collect real-world data. The researchers see if the data match what the model predicts, or if the mathematical model needs to be refined.

Rychtář's work with undergrad students during the summer research projects is just a fraction of his math biology work. He has other collaborators on campus, as well as at universities around the world. He's working on projects related to plant-pollinator interactions with researchers in China, cockroach behavior with zoologists in the Czech Republic, and disease vectors with faculty at UNCG and Bennett College.

He has also co-authored a book with Mark Broom from City University London called *Game-Theoretical Models in Biology*. Game theory, the study of optimal decision making, was made famous by mathematician John Nash, the subject of the movie *A Beautiful Mind*. It has traditionally been applied in economics, but it also applies to all sorts of biological questions — including honeybee mating.

"What sort of mathematics is used to solve the problems is not that important," Rychtář says. "It's the application of mathematics that is important."

BUILDING A BETTER MOUSETRACK **Kalcounis-Rueppell and Pauli created software to identify and track mouse movements in thermal video recordings.**

SEEDING INTERDISCIPLINARY COLLABORATIONS

It's those applications that drive the interdisciplinary work that is the hallmark of math biology.

A just-funded project will bring UNCG math faculty and graduate students together with biology professors and graduate students from other universities to examine animal movements near habitat boundaries.

Ecologists have studied for decades what drives such movements — changes in the environment, food supplies, predation, and more.

Shivaji, working with collaborators at Louisiana State University and Auburn University-Montgomery, has won federal funding to study how boundaries affect migration patterns and behavior. Boundaries, in this case, are the edges of a region that's hospitable to an animal.

The goal is to develop mathematical models that describe three major scenarios:

- **WHAT HAPPENS WHEN AN ANIMAL GETS CLOSE TO A BORDER? WHAT AFFECTS ITS DECISION TO CROSS OR NOT CROSS?**
- **WHAT FACTORS INFLUENCE ANIMALS THAT MOVE BETWEEN TWO REGIONS THAT ARE SEPARATED BY AN INHOSPITABLE AREA?**
- **WHY DO TWO SPECIES THAT DON'T INTERACT INSIDE A REGION COMPETE AT A BOUNDARY?**

The math, Shivaji says, that describes this will be a reaction-diffusion process — a type of differential equation. Reaction-diffusion equations are used in physics and engineering, for example, to understand how heat spreads through a surface.

Animal behavior near a boundary represents a similar model. Animals diffuse (move) through the region, but what happens when they get to the boundary? What factors cause different responses?

While Shivaji, working with PhD students at UNCG and his collaborators in Alabama, develops mathematical models, his collaborators in Louisiana will be working in the field to collect real-world data about actual animal movements in these environments.

The researchers will study two species of insects — delphacid planthoppers and blessed bugs — that live in the salt marshes of the Atlantic and Gulf coasts. Both species feed on smooth cordgrass, which often grows in patches, creating, in effect, habitats for the insects that are separated by boundaries of water, sand, or other marsh terrain.

The data will be used to refine the mathematical models. If successful, the research could give biologists mathematical tools to predict how these species move about in the wild in varying circumstances. And over time, it might lead to mathematical models that allow scientists to describe the movements of all sorts of animals in all sorts of environments. Shivaji and his collaborators also plan to develop models that focus on predation and harvesting.

Such models will have a variety of applications. Resource management, for example. Fisheries managers have to decide how many fish fishermen should be able to catch. Those calculations could be improved if biologists had better tools for understanding the impact of fishing and other factors on fish populations.

Just as important as the scientific advances that come out of the boundary work will be the opportunities it provides for a new generation of scientists to work across disciplinary lines.

"Our way of thinking, in this particular proposal, is that from the start of undergraduate and the graduate level research we want to start that interaction," Shivaji says. The grant funding requires one-week workshops — one at LSU and one at UNCG — where the students and faculty learn more about each other's fields.

For Shivaji — decades into his career as a mathematician — this project will be his first foray into work that includes collaborations with biologists. His hope is that for his students it will be the beginning of many such collaborations that shape their careers.

By Mark Tosczak • Photography by Mike Dickens • Learn more:
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